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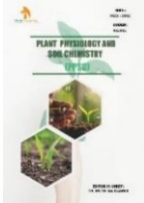

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RESEARCH ARTICLE

EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON SOIL PROPERTIES GROWTH, AND YIELD OF SOYBEAN (*Glycine max L.)* AT MANGALPUR, CHITWAN, NEPAL

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ABSTRACT

Integrated nutrient management requires a careful and balanced application of different nutrient sources like biofertilizers, organic, and chemical fertilizers for effective crop and sustainable soil management. A field experiment was carried out from July 2022 to November 2022 to study the effect of integrated nutrient application on soil properties, growth, and yield of soybean (*Glycine max l.)* in Mangalpur, Chitwan, Nepal. The soil was sandy loamy in texture and acidic in nature. The experiment was laid out in a two-factor randomized complete block design with three replications consisting of two biofertilizers (Bradyrhizobium and phosphate-solubilizing bacteria) and various recommended doses of phosphatic fertilizer from chemical and organic sources. Results revealed that the use of Bradyrhizobium and phosphorus solubilizing bacteria had significantly greater effect on total soil nitrogen (0.131%), soil available phosphorus (47.89 kg ha^{-1}), plant height (62.85 cm), number of nodules, dry weight of root nodules, number of pods per plant (48.25), seeds per plant (136.66), thousand seed weight (153.75 g), and yield (11.81 qt ha^{-1}) respectively. The combination of 30% pelleted poultry manure + 70% recommended dose of chemical phosphorus had a significantly lower effect on soil pH. Similarly, 100% recommended dose of chemical phosphorus, 30% pelleted poultry manure +70% recommended dose of chemical phosphorus, and 30% mashed poultry manure+70% recommended dose of chemical phosphorus had a significantly greater effect on soil available phosphorus, plant height, number of branches and leaflets at maturity, number of nodules at various growth stages, number of seeds per plant, thousand seed weight and yield respectively. Overall, the findings highlight the potential benefits of integrating bradyrhizobium and PSB with appropriate recommended doses of phosphorus, which can thus be recommended to farmers of Mangalpur, Chitwan, for optimizing soybean production.

KEYWORDS

Biofertilizer, Inoculation, Nitrogen, Poultry manure, Soybean

1. INTRODUCTION

Agricultural systems are globally experiencing a paradigm change that is moving them toward sustainability and environmental responsibility. As the Nepalese people are highly dependent on farming, conventional farming practices are under pressure as the world's population grows and so does the need for food and agricultural products (Ghimirey et al., 2023; Acharya et al., 2023). In this situation, maximizing agricultural yield while maintaining the long-term health of ecosystems and soils is critical. The integrated application of both organic and inorganic nutrient sources is a potential way to preserve productivity balance, activity of beneficial soil-dwelling creatures, enhance the soil's long-term capacity to supply and cycle nutrients, enhance soil tilth, and maintain (Marahatta et al., 2024). In addition, it also conserves biological diversity and functions above and below ground and avoids chemical toxicity (Ghimirey et al., 2024a). This approach promotes sustainable agriculture (Weil and Brady, 2016).

To meet the nutrient demands of crops, conventional agricultural practices have traditionally relied heavily on chemical fertilizers, neglecting postharvest techniques to obtain food self-sufficiency (Chaurasia et al., 2020; Prachand et al., 2025). But the constant use of these fertilizers has given rise to several issues, such as pollution of the environment, nutrient imbalances, and degraded soil (Galloway et al., 2003; Lal, 2004). In addition to chemical imbalances that disrupt microbial communities and nutrient cycling, physical consequences include erosion, compaction, and loss of soil organic matter (Weil and Brady, 2016; Chaurasia et al., 2024a). It has become more popular to incorporate organic inputs, such as chicken manure and biofertilizers, into nutrient management strategies in response to these difficulties. Increased soil structure and nutrient content can be achieved by adding poultry manure, which is an abundant supply of organic matter, macronutrients, and micronutrients (Dróżdż et al., 2020).

On the other hand, bio-fertilizers introduce advantageous microorganisms that promote nutrient availability, increase plant growth, and enhance soil health (Bashan and de-Bashan, 2010; Ghimirey et al., 2024b). Pellets and mash made from poultry dung are two of the most well-liked and accessible non-chemical fertilizers for farmers. It has more nutrients, mainly potassium, phosphorus, and nitrogen. Fresh chicken manure can be substituted with mashed and pelleted manure. Fresh chicken manure is difficult to handle and transport because it burns seeds and seedlings and may contain harmful bacteria. Fresh chicken manure has a burning effect because it contains highly concentrated fertilizer that pulls vital moisture from the plants, giving the appearance that they are experiencing a drought until their leaves turn yellow and eventually wither away. However, because industrially produced poultry mashes and pellets are sterilized during manufacturing, there is a lower risk of plant burning and pathogen infestation (Parajuli et al., 2022).

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Because organic matter can offer nutrients, it has a direct impact on crop development and yield. The physical characteristics of the soil, such as aggregate stability and porosity, which can enhance the root environment and promote plant growth, are also indirectly impacted (Sharma and Kumar, 2023). A group researchers research has shown that incorporating crop wastes or organic manures into the soil can increase its water-holding capacity, decrease bulk density and speed up infiltration rate (Eden et al., 2017; Khadim et al., 2024; Adhikari et al., 2022). However, neither organic nor inorganic fertilizers alone can maintain productivity. Agricultural technicians and farmers both have suggested their proper application is necessary to protect soil health, increase productivity, and improve input use efficiency (Bandyopadhyay et al., 2010; Chaurasia et al., 2023).

Soybean cultivation, a leguminous crop high in protein, frequently encounters difficulties due to inadequacies in soil nutrients, specifically nitrogen and phosphorus (Bagale, 2021). Increasing soybean yield and maintaining soil quality is possible by applying an integrated nutrient management strategy that combines chemical fertilizers, biofertilizers, and chicken manure (Selim, 2020). Substantial evidence suggests that soybeans can lower the amount of nitrogen fertilizer needed for a subsequent crop. Nitrogen dioxide (N_2) fixation potential in soybeans varies, with an average of about 84 kg N ha^{-1} and a range of 0 to 185 kg N ha^{-1} (Ciampitti et al., 2021).

Soybeans rank fourth in the world's major crops in terms of output volume. Over 85% of the crop is crushed to create soybean meal and oil, with the remaining portion being used directly. Because of its high protein content, soybean meal is mainly utilized as animal feed, while soybean oil is largely used in food consumption and, in recent times, for applications such as biodiesel (Dilawari et al., 2022). Between 1968 and 2018, the total area planted for soybeans expanded by 4.3 times, from 28.8 million hectares (ha) to approximately 125 million ha. During this time, the average yield of soybeans nearly doubled (Pokhrel, 2021). With almost 10% of the global agricultural trade value, the combined trade of soybeans and their derivatives is the most significant in the agricultural industry. The international commerce of soybeans and soybean products has grown significantly since the early 1990s; in 2008–2009, it overtook the trade of wheat and coarse grains (Giraudo, 2020). The USDA Agricultural Projections to 2025 predict that by that year, the world's soybean commerce will have increased by 22% for soybean oil, 20% for soybean meal, and 30% for soybean meal (Dohlman et al., 2025).

With over 80% of the world market for soybean exports going to the United States and Brazil, these two countries lead the way (Wilson, 2008). As the world's top exporter of soybeans, Brazil is expected to increase its shipments by 35 percent to reach 76.4 million tons between 2016–17 and 2025–2026. The second-largest exporter, the United States, is anticipated to increase its soybean exports by 6% during that time to a total of 52.4 million tons (Morales et al., 2023). Because of rising incomes, shifting dietary preferences, and a booming pork and poultry business, Southeast Asia's demand for soybean meals is expanding quickly (Goldsmith, 2008). It is anticipated that over the next ten years, Southeast Asia's imports of soybean meal will increase significantly, amounting to 6.7 million tons by 2025–2026. This growth will make up almost half of the anticipated increase in the trade of soybean meal worldwide (Dohlman et al., 2025).

While research on the individual effects of chemical fertilizers and poultry manures on crop development and soil properties has been conducted, comprehensive studies on the combined effects of chemical fertilizers and poultry manures on crop growth and soil properties are relatively rare. It is hypothesized that the physical and chemical characteristics of the soil, which are enhanced by the addition of manure, also affect crop growth features, including biomass production, root growth traits, leaf area index, and partitioning, all of which have an impact on the productivity and efficiency of soybean input utilization. This study has multiple ramifications because it looks at how fertilizers- poultry dung, chemical fertilizers, and biofertilizers- affect soil characteristics, yield, and soybean growth. The findings could provide valuable insights for farmers and agricultural practitioners seeking sustainable nutrient management strategies that balance productivity with soil health improvement. Moreover, the study's contributions to understanding the intricate interactions between integrated nutrient management and soil properties will serve as a foundation for future research and policy decisions in the realm of sustainable agriculture.

2. Material and Methods

2.1 Description of experimental site

2.1.1 Location of experimental site

This study was carried out in the experimental field of Mangalpur, Chitwan, during the years July 2022 to November 2022 (Figure 1). The experimental site's soil had medium levels of phosphorus, low quantities of organic matter, a somewhat acidic pH, and lower levels of potassium and nitrogen.

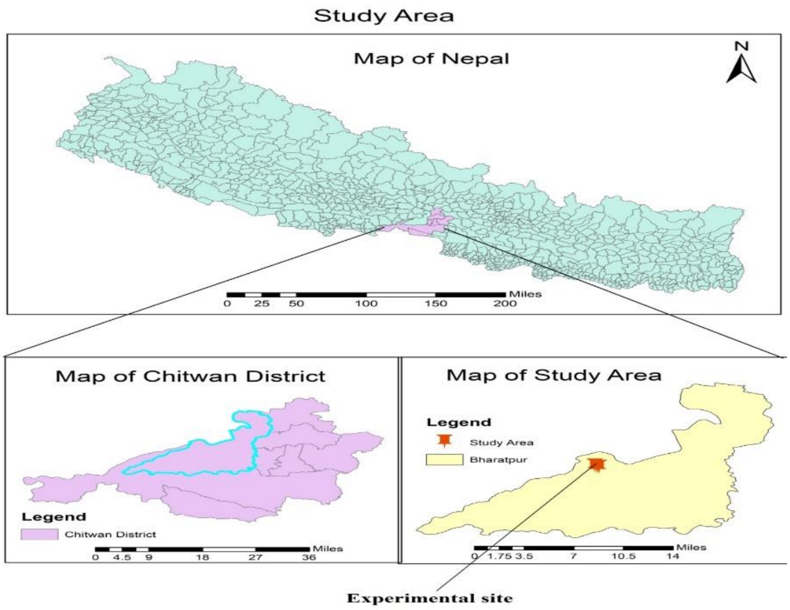

Figure 1: Map of experimental site at Mangalpur, Chitwan.

2.1.2 Cropping history

The experiment was carried out at a field in Mangalpur, Chitwan, where maize had been planted for the previous two years.

2.1.3 Soil properties of the experimental site

The composite samples from different spots representing each replication of the experiment were collected with a soil auger at 0-20 cm soil depth before starting the experiment. The soil sample was taken, allowed to air dry, ground, and sieved using a 2 mm sieve before being examined to determine the basic physical and chemical characteristics of the soil at the experimental site. The available soil nitrogen was measured using a Kjeldhal distillation unit the available phosphorus and potassium were measured using spectrophotometers the organic matter was measured using the Walkey and Black method the pH (1:2 soil: water suspensions) was measured using a Beckman Glass Electrode pH meter and the soil texture was measured using a hydrometer (Jackson, 1967; Olsen, 1954; Black et al., 1965; Walkley and Black, 1934; Wright, 1935). Table 1 displays the physical and chemical characteristics of the soil at the testing site. The texture of the soil was sandy loamy.

Available organic matter, total soil nitrogen, available phosphorus, and available potassium were noted with the chemical characteristics of the soil. In the experimental field, the average pH of the soil was determined to be somewhat acidic (pH 5.8). While reduced soil organic matter showed low soil fertility, accessible nitrogen in the field represented medium seen in the study of phosphorus in the medium, and low potassium as mentioned in Table 1 (Khatri-Chhetri, 1991).

Table 1: Physical and chemical properties of the experimental soils.

Soil Properties	Block Number			Rating	Analysis Methods
	1	2	3		
Bulk Density (g cm^{-3})	1.36	1.38	1.36		Core Ring Method
Soil texture				Sandy Loam	Hydrometer Method
Sand (%)	57.70	57.70	55.7		
Silt (%)	30.85	30.85	32.95		
Clay (%)	11.45	11.45	11.35		
Soil pH	5.92	5.78	5.7	Acidic	Beckmann electrode pH meter method
SOM (%)	1.8	2.18	2.36	Low	Walkley and Black Method
Total soil nitrogen (%)	0.09	0.11	0.12	Medium	Kjeldahl distillation method
Available P (kg ha^{-1})	39.21	94.94	37.64	Medium to High	Modified Olsen bicarbonate method
Available K (kg ha^{-1})	62.40	67.20	52.80	Low	Ammonium acetate extraction method

2.1.4 Climatic condition of the experiment site

The necessary agrometeorological data, such as the highest and lowest temperatures (⁰C), relative humidity (%), rainfall (mm), etc., were acquired from the National Maize Research Program's agrometeorological stations in Rampur, Chitwan, as shown in Figure 2.

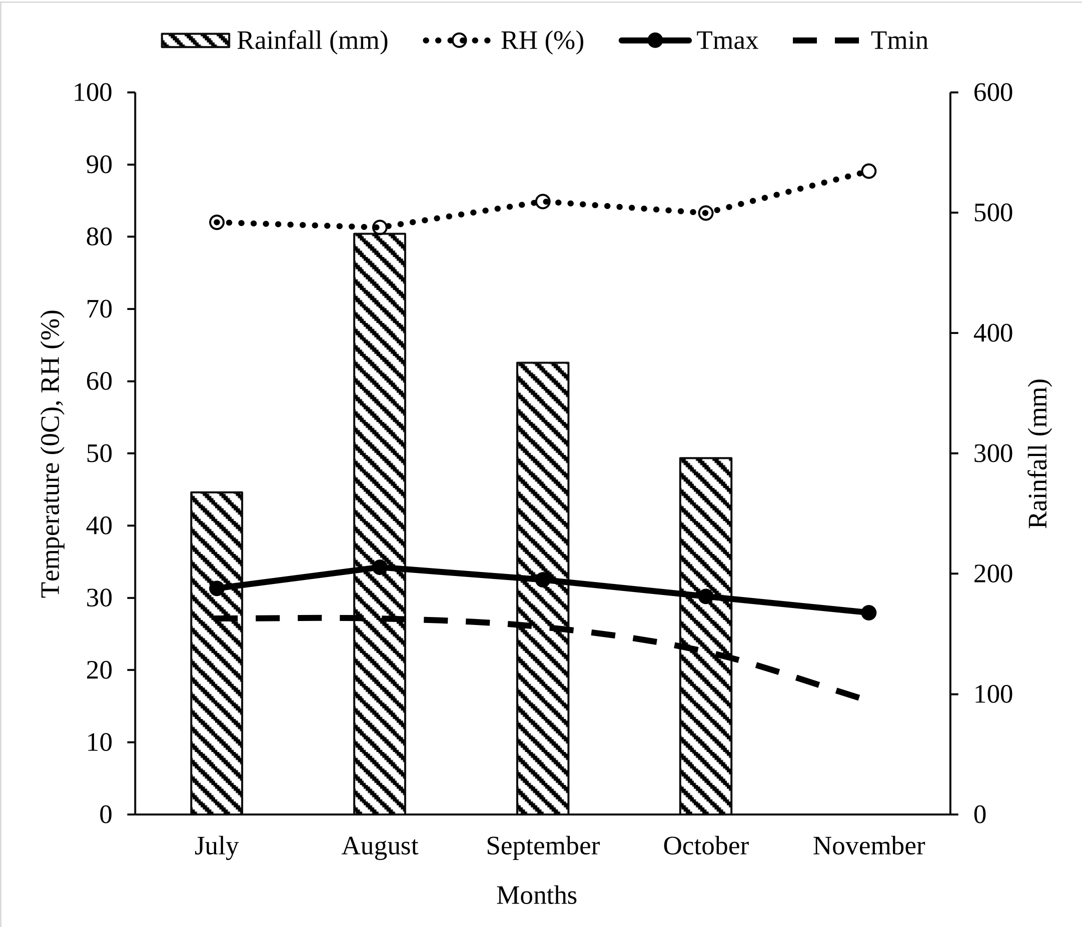

Figure 2: Relative humidity, maximum temperature, minimum temperature, and rainfall of Mangalpur, Chitwan, from July 2022 to November 2022.

Note: RH (%) = Relative Humidity (%), Tmin= Minimum Temperature, Tmax= Maximum Temperature

2.2 Experimental details

2.2.1 Experimental design and layout

A double factorial Randomized Complete Block Design (RCBD) was used, involving two bio-fertilizer applications, seven rates of different sources of nutrients, and three replications as illustrated in Figure 3.

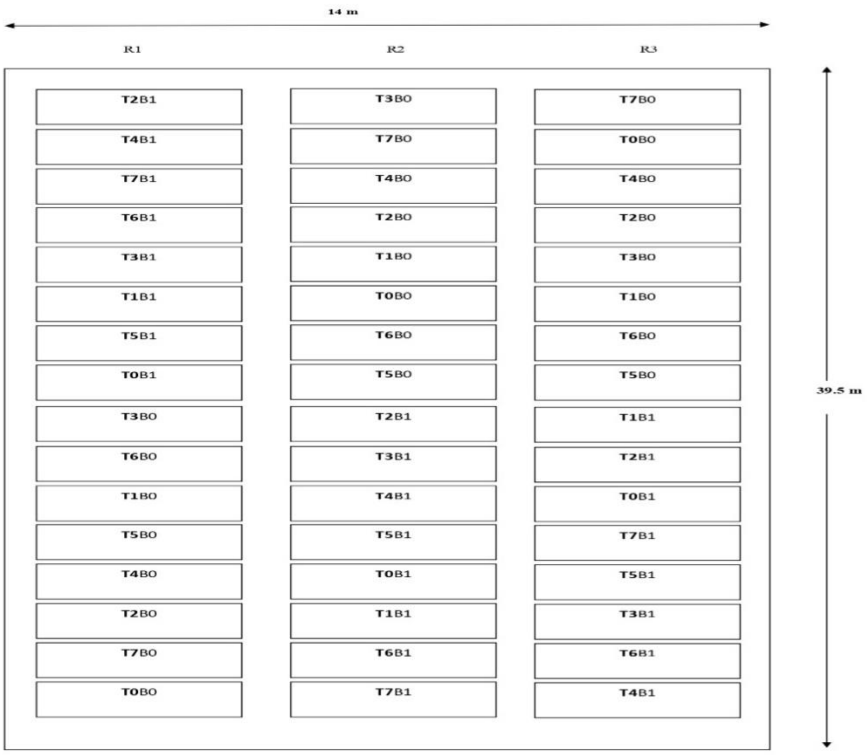

Figure 3: Field layoutof the experimental site at Mangalpur, Chitwan, in 2022

2.2.2 Treatment details

The treatments include the combination of different levels of RD of phosphorus for soybean and two biofertilizers, i.e., Bradyrhizobium and phosphate-solubilizing bacteria (PSB), along with no use of any biofertilizers as shown in Table 2. The treatments were distributed at random within each block to minimize experimental mistakes.

Table 2: Treatments used in the experimental trial

S.N.	Factors	Treatments	Details
1.	No biofertilizer (B0)	T0B0	Control
		T1B0	30% Pelleted poultry + 70% RD of chemical P
		T2B0	30% Mashed poultry + 70% RD of chemical P
		T3B0	60% Pelleted poultry + 40% RD of chemical P
		T4B0	60% Mashed poultry + 40% RD of chemical P
		T5B0	100% Pelleted poultry manure
		T6B0	100% Mashed poultry manure
		T7B0	100% RD of chemical P
2	Integrated dose of chemical fertilizer (B1)	T0B1	Bio-fertilizer (Bradyrhizobium + PSB)
		T1B1	30% Pelleted poultry + 70% RD of chemical P + Bio-fertilizer
		T2B1	30% Mashed poultry + 70% RD of chemical P + Bio-fertilizer
		T3B1	60% Pelleted poultry + 40% RD of chemical P + Bio-fertilizer
		T4B1	60% Mashed poultry + 40% RD of chemical P + Bio-fertilizer
		T5B1	100% Pelleted poultry + Bio-fertilizer
		T6B1	100% Mashed poultry + Bio-fertilizer
		T7B1	100% RD of chemical P + Bio-fertilizer

The pelleted poultry manure used in our experiment had a nutrient content of Nitrogen (3.91%), P_2O_5 (4.65%), and K_2O (3.83%); and mashed poultry manure used in the experiment had a nutrient content of Nitrogen (3.91%), P_2O_5 (5.41%), and K_2O (3.89%) as shown in Table 3.

Table 3: Sources and their nutrient contents

Organic Sources	% of nutrients		
	Nitrogen (%)	P_2O_5 (%)	K_2O (%)
Pelleted poultry manure	3.91 %	4.65%	3.83%
Mashed poultry manure	3.91%	5.41%	3.89%

2.2.3 Field layout

A 14 x 39.5 m² field that had been planted to maize the previous two years was chosen. The field was completely ploughed twice with a tractor to prepare the seedbed properly, and it was left that way for the following two weeks. The net plot size of 4 × 2 m² was maintained based on the field's dimensions, and each plot was constructed per the treatments.

The National Agricultural Research Centre (NARC), Rampur, Chitwan, provided the soybean cv. "Puja" seeds, while the Agrovet, Tadi, and Chitwan, provided the rhizobium and PSB (phosphorus-solubilizing bacteria) inoculum. Before sowing, seeds were inoculated using the method described (Fatima et al., 2007b). All that was done was to surface sterilize the seeds for two minutes in an aqueous mercuric chloride solution (0.1%) and then completely rinse them with distilled water. Following a six-hour soak in distilled water, seedlings were inoculated with biofertilizer strains.

The treatments include biofertilizer strains (with and without mixtures of biofertilizer strains designated as B1 and B0); control and various sources of phosphorus, such as 30% poultry mash + 70% RD of chemical phosphorus, 60% poultry pellet + 40% RD of chemical phosphorus, 100% poultry pellet, 100% poultry mash, 100% RD of chemical phosphorus and designated as T1, T2, T3, T4, T5, T6, T7 and T8 respectively, while the control group is designated as T0; one soybean variety, namely Puja.

The two-factor randomized complete block design was used to set up the experiment. Chemical fertilizers such as urea, single super phosphate, and muriate of potash (MOP) were used to apply the basal doses of N, P, and K. Mashed and pelleted poultry manure were also utilized as the source of NPK. The control group consisted of untreated seeds and fertilised plots without any fertilizer applied. On June 21, 2022, seeds were manually spread in each plot, with 50 x 10 cm spacing and a 3–4 cm depth between each row. The plant population was maintained by gap-filling and thinning after germination. Whenever needed, hoeing was used to get rid of the weeds.

At various growth stages, a group of three plants from each plot was chosen at random for their nodulation potential (number of nodules, dry weight of nodules). Plants were carefully picked for nodulation by washing them clean of soil and excavating the roots. After being cut off from the roots, the nodules were tallied and dried in a desiccator for dry-weight storage. The yield attributes, such as the number of pods, the weight of 1000 seeds, and seed yield, were recorded at the end of the growth season.

2.3 Statistical analysis

Using a two-factorial Randomized complete block design (RCBD), growth, nodulation, yield, and soil characteristics were measured and statistically analyzed. If analysis of variance revealed significant treatment effects, Duncan's Multiple Range Tests, or DMRTs, were used to compare the means at the 5% level of significance (Steel and Torrie, 1980). The data was successfully gathered, and Office Package 2019 (MS-Excel sheet) was utilized for data input, tables, charts, graphs, and basic statistical analysis. The obtained data were analyzed using ANOVA and Least Significant Difference (LSD) methods, drawing from the work of (Gomez and Gomez, 1984). R-stat (version 3.6.1) was used to perform statistical analysis on the data using two-way ANOVA.

3. Results

3.1 Soil parameters

3.1.1 Soil pH

The soil pH was significantly influenced by the bio-fertilizer application (Table 4). The lowest soil pH was recorded in bio-fertilizer-applied soil (5.35), while a higher soil pH was recorded in the control (5.66). Similarly, the combined dose of fertilizer application had a major impact on the pH of the soil. The highest soil pH was recorded in the control (5.65), which was on par with mashed poultry manure (5.61). The lowest soil pH was recorded on the combination of 30% pelleted poultry manure and 70% RD of chemical P (5.36).

3.1.2 Soil organic matter

In Table 4, the data displays the amount of organic matter in the soil following the soybean harvest. Soil organic matter had a mean value of 2.19. Neither the integrated dose of fertilizer application nor the application of biofertilizer significantly affects the amount of organic matter in the soil.

3.1.3 Bulk density

The data on bulk density after the harvest of soybeans is shown in Table 4. The mean value of bulk density was 1.47. Both the integrated fertilizer dose and the biofertilizer application had no discernible effects on the bulk density of the soil.

Table 4: Soil pH, soil organic matter, bulk density as influenced by biofertilizers, poultry manures, and chemical fertilizers at Mangalpur, Chitwan, Nepal 2022

Treatment	pH	Soil organic matter	Bulk density
Biofertilizer			
No Inoculation	5.66^{a}	2.19	1.376
With Inoculation	5.35^{b}	2.18	1.371
LSD	0.035	0.06	0.009
SEM	0.012	0.02	0.003
P value	**	NS	NS
Integrated Recommended Dose			
100% RD of P	5.36^{e}	2.16	1.375
30%Pellet+70% RD of P	5.45^{d}	2.18	1.368
30%Mash+70% RD of P	5.46^{d}	2.2	1.372
60%Pellet+40% RD of P	5.45^{d}	2.2	1.380
60%Mash+40% RD of P	5.50^{cd}	2.18	1.378
100% Pellet	5.57^{bc}	2.2	1.381
100% Mash	5.61^{ab}	2.19	1.370
Control	5.65^{a}	2.19	1.366
LSD	0.07	0.11	0.018
SEM	0.024	0.04	0.006
P value	**	NS	NS
CV	1.08	4.5	1.135
Grand mean	**5.51**	**2.19**	**1.37**

Notes: SEM (±) = Standard Error of mean, LSD=Least Significant Difference, CV = Coefficient of Variation, RD = Recommended Dose, Means followed by different letters within the same column are significantly different at least 5% DMRT, NS and ** indicate non-significant and significant at P<0.01 respectively.

3.1.4 Total soil nitrogen

Total soil nitrogen had a mean value of 0.126%. The total soil nitrogen content was influenced by bio-fertilizer application. Higher soil nitrogen content was recorded in bio-fertilizer-inoculated soil (0.131%) than in soil with no inoculation (0.121%). Similarly, the integrated dose of fertilizer applications did not affect soil nitrogen content (Table 5).

3.1.5 Soil available phosphorus

The data on soil available phosphorus after the harvest of soybeans is shown in Table 5. The average amount of phosphorus available in the soil was 46.17 kg ha^{-1}. The application of biofertilizer affected the amount of phosphorus that was accessible in the soil. The highest soil available phosphorus was recorded in bio-fertilizer applied to soil (47.89 kg ha^{-1}) than in non-inoculated soil (44.46 kg ha^{-1}). Similarly, the available phosphorus was influenced by the integrated dose of fertilizer applications. The highest soil's available phosphorus was recorded in 30% mashed poultry manure +70% RD of P (48.53 kg ha^{-1}), which was on par with 30% pelleted poultry manure +70% RD of P (48.38 kg ha^{-1}) and 100% RD of P (48.02 kg ha^{-1}).

3.1.6 Soil available potassium

The data on the soil's available potassium after the harvest of soybeans is shown in Table 5. The average amount of potassium available in the soil was 60.93 kg ha^{-1}. Both the integrated dose of fertilizer application and the application of biofertilizer did not significantly affect the amount of potassium available in the soil.

Table 5: Total soil nitrogen, available phosphorus, and available potassium as influenced by biofertilizers, poultry manures, and chemical fertilizers at Mangalpur, Chitwan, Nepal, 2022

Treatment	Total soil nitrogen (%)	Available Soil phosphorus (kg ha^{-1})	Available soil potassium (kg ha^{-1})
Biofertilizer			
No Inoculation	0.121^{b}	44.46^{b}	61.59
With Inoculation	0.131^{a}	47.89^{a}	60.26
LSD	0.007	1.44	1.42
SEM	0.003	0.501	0.494
P value	**	***	NS
Integrated Recommended Dose			
100% RD of P	0.135	48.38^{a}	61.73
30%Pellet+70% RD of P	0.135	47.78^{ab}	60.05
30%Mash+70% RD of P	0.128	48.53^{a}	62.00
60%Pellet+40% RD of P	0.125	45.01^{bc}	60.47
60%Mash+40% RD of P	0.128	44.5^{c}	60.29
100% Pellet	0.12	45.36^{bc}	61.2
100% Mash	0.12	45.22	61.24
Control	0.11	44.64^{c}	60.42
LSD	0.007	2.89	1.42
SEM	0.005	1.001	0.987
P value	NS	*	NS
CV	10.22	5.31	3.97
Grand mean	0.126	46.17	60.93

Notes: SEM(±) = Standard Error of mean, LSD=Least Significant Difference, CV = Coefficient of Variation, RD = Recommended Dose, Means followed by different letters within the same column are significantly different at least 5% DMRT, NS, *, **,*** indicates non-significant, significant at 5%, significant at 1%, and significant at 0.01% respectively

3.2 Plant parameters

3.2.1 Plant height

For soybean plants, bio-fertilizers had no significant effect on plant height at 30 DAS, 60 DAS, or 90 DAS, while plant height was found to be significantly different in bio-fertilizer-inoculated soils at 120 DAS. Plant height at 120 DAS was recorded as higher in bio-fertilizer-inoculated soils (62.85 cm) than in non-inoculated ones (61.21 cm). Similarly, the integrated dose of fertilizers did not have any significant impact on the plant height of soybean at 30DAS, while significant impact was found at 60DAS, 90DAS, and 120DAS. Plant height at 60 DAS was recorded highest in30% pelleted poultry manure + 70% RD of P (38.21 cm) which was at par with 30% mashed poultry manure + 70% RD of P (38.11 cm), 100% RD of P (37.96 cm), 60% pelleted poultry manure+40% RD of P (37.52 cm), 60% mashed poultry manure +40% RD of P (37.12 cm), and 100% pelleted poultry manure (36.92 cm) respectively. Plant height at 90 DAS was recorded highest in 100% RD of P (55.55 cm), which was at par with 30% pelleted poultry manure+ 70% RD of P (5.43 cm). Plant height at 120 DAS was recorded as highest in 100% RD of P (65.92cm). Plant height was seen as lowest in control at all stages of growth compared to other treatments (Table 6).

Table 6: Plant height at 30DAS, 60DAS, 90DAS, and 120DAS as influenced by biofertilizers, poultry manures, and chemical fertilizers at Mangalpur, Chitwan, Nepal, 2022

Treatment	Plant height			
	30DAS	60DAS	90DAS	120DAS
Biofertilizer				
No Inoculation	20.09	36.93	50.78	61.21^{b}
With Inoculation	20.41	37.46	52.32	62.85^{a}
LSD	0.49	0.71	1.61	1.43
SEM	0.169	0.246	0.56	0.49
P value	NS	NS	NS	*
Integrated Recommended Dose				
100% RD of P	20.52	37.96^{a}	55.43^{a}	65.92^{a}

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Table 6 (cont): Plant height at 30DAS, 60DAS, 90DAS, and 120DAS as influenced by biofertilizers, poultry manures, and chemical fertilizers at Mangalpur, Chitwan, Nepal, 2022

30%Pellet+70% RD of P	20.42	38.21^{a}	55.55^{a}	63^{b}
30%Mash+70% RD of P	20.05	38.11^{a}	52.08^{b}	62.42^{b}
60%Pellet+40% RD of P	20.37	37.52^{ab}	52.21^{b}	62.62^{b}
60%Mash+40% RD of P	20.62	37.12^{ab}	50.29^{b}	61.25^{bc}
100% Pellet	19.9	36.92^{ab}	49.15^{bc}	60.8^{bc}
100% Mash	20.42	36.28^{bc}	50.76^{b}	61.05^{bc}
Control	19.69	35.41^{c}	46.95^{c}	59.17^{c}
LSD	0.98	1.42	3.22	2.85
SEM	0.34	0.49	1.11	0.99
P value	NS	**	***	**
CV	4.1	9.08	5.29	3.91
Grand mean	20.25	37.19	51.55	62.03

Notes: SEM (±) = Standard Error of mean, LSD=Least Significant Difference, CV = Coefficient of Variation, RD = Recommended Dose, Means followed by different letters within the same column are significantly different at least 5% DMRT, NS, *, **, *** indicates non-significant, significant at 5%, significant at 1%, and significant at 0.01% respectively

3.2.2 Number of branches and number of leaflets

In Table 7, the data displays information on the quantity of branches and leaflets on soybeans at harvest. The number of branches that soybeans had at maturity was significantly impacted by the integrated dose of fertilizers, however, biofertilizers had no significant effect. The number of branches was recorded highest in 30% pelleted poultry manure +70% RD of P (20.5) which was at par with 100% RD of P (20.33), 30% mashed poultry manure+70% RD of P (20.17), 60% pelleted poultry manure +40% RD of P (19.83), 100% pelleted poultry manure(19.83) and 100% mashed poultry manure (19.83) respectively, while lowest was recorded in control among all the treatments (19.17).

Similarly, the number of leaflets at maturity was not significantly impacted by biofertilizers. The number of leaflets was recorded highest in 100% RD of P (29.83), which was at par with 30% pelleted poultry manure + 70% RD of P (28.83), while the lowest was seen in the control (24.33).

Table 7: Number of branches and number of leaflets at maturity as influenced by biofertilizers, poultry manures, and chemical fertilizers at Mangalpur, Chitwan, Nepal, 2022

Treatment	Number of branches	Number of leaflets
Biofertilizer		
No Inoculation	19.83	26.92
With Inoculation	19.96	27.13
LSD	0.38	0.7
SEM	0.131	0.24
P value	NS	NS
Integrated Recommended Dose		
100% RD of P	20.33^{a}	29.83^{a}
30%Pellet+70% RD of P	20.5^{a}	28.83^{a}
30%Mash+70% RD of P	20.17^{ab}	26.83^{b}
60%Pellet+40% RD of P	19.83^{abc}	27.00^{b}
60%Mash+40% RD of P	19.5^{bc}	26.00^{b}
100% Pellet	19.83^{abc}	27.33^{b}
100% Mash	19.83^{abc}	26.00^{b}
Control	19.17^{c}	24.33^{c}
LSD	0.75	1.39
SEM	0.262	0.48
P value	*	***
CV	3.22	4.4
Grand mean	**19.89**	**27.02**

Notes: SEM(±) = Standard Error of mean, LSD=Least Significant Difference, CV = Coefficient of Variation, RD = Recommended Dose, Means followed by different letters within the same column are significantly different at least 5% DMRT, NS, *, *** indicates non-significant, significant at 5%, and significant at 0.01% respectively

3.2.3 Number of nodules

Bio-fertilizers did not have any significant impact on the number of nodules of soybean at 30 DAS, while they had a significant impact on 60 DAS, 90 DAS, and 120 DAS, respectively. The number of nodules was recorded highest in bio-fertilizer inoculated soils at 60 DAS (41.34), 90 DAS (11.84), and 120 DAS (3.03) respectively than in non-inoculated soils.

Similarly, the number of soybean nodules was not significantly impacted by the integrated dose of fertilizers at 30DAS, 60DAS, and 90DAS, respectively, while it had a significant impact on 120DAS. The number of nodules at 120 DAS was recorded as highest in 100 % NPK (3.53), which was at par with 30% Poultry Pellet + 70% RD of P (3.33). The number of nodules was seen as lowest in control than other treatments at all stages of growth, as mentioned in Table 8.

Table 8: Total number of root nodules as influenced by biofertilizers, poultry manures, and chemical fertilizers at Mangalpur, Chitwan, Nepal, 2022

Treatment	Number of Nodules			
	30DAS	**60DAS**	**90DAS**	**120DAS**
Biofertilizer				
No Inoculation	18.84	34.07[b]	8.92[b]	2.84[b]
With Inoculation	19.17	41.34[a]	11.84[a]	3.03[a]
LSD	0.91	2.64	2.00	0.171
SEM	0.316	0.92	0.69	0.059
P value	NS	***	**	*
Integrated Recommended Dose				
100% RD of P	19.63	41.13	13.31	3.53[a]
30%Pellet+70% RD of P	19.15	39.15	11.2	3.33[ab]
30%Mash+70% RD of P	18.97	38.82	10.4	3.11[bc]
60%Pellet+40% RD of P	18.85	37.98	10.57	2.89[cd]
60%Mash+40% RD of P	18.7	37.77	10.74	2.96[cd]
100% Pellet	19.05	37.33	9.2	2.72[d]
100% Mash	18.9	36.48	9.75	2.65[d]
Control	18.78	32.98	7.86	2.29[e]
LSD	1.82	5.28	4.01	0.34
SEM	0.631	1.83	1.39	0.119
P value	NS	NS	NS	***
CV	8.13	11.88	32.74	9.9
Grand mean	**19.00**	**37.7**	**10.37**	**2.94**

Notes: SEM(±) = Standard Error of mean, LSD=Least Significant Difference, CV = Coefficient of Variation, RD = Recommended Dose, Means followed by different letters within the same column are significantly different at least 5% DMRT, NS, *, **, *** indicates non-significant, significant at 5%, significant at 1%, and significant at 0.01% respectively

3.2.4 Dry weight of nodule per plant

Bio-fertilizers did not have any significant impact on the dry weight of nodules at 30 DAS, while they had a significant impact at 60 DAS, 90 DAS, and 120 DAS, respectively. The dry weight of root nodules was recorded as higher in bio-fertilizer-inoculated soils at 60DAS (88.78 mg), 90DAS (15.19 mg), and 120DAS (4.27 mg), respectively, than in non-inoculated soils (Table 9).

Similarly, bio-fertilizers did not have any significant impact on the dry weight of nodules of soybean at 30 DAS, 60 DAS, and 90 DAS, respectively while it had a significant impact on 120 DAS. The dry weight of nodules of soybean at 120 DAS was recorded as highest in 40% RD of P (5.17 mg). The dry weight of nodules was seen lowest in control at all stages of growth.

Table 9: Dry weight of root nodules as influenced by biofertilizers, poultry manures, and chemical fertilizers at Mangalpur, Chitwan, Nepal, 2022

Treatment	Dry weight of nodule (mg)			
	30DAS	**60DAS**	**90DAS**	**120DAS**
Biofertilizer				
No Inoculation	21.97	73.26[b]	12.17[b]	3.87[b]
With Inoculation	24.77	88.78[a]	15.19[a]	4.27[a]
LSD	4.17	5.4	2.00	0.22
SEM	1.44	1.87	0.69	0.07
P value	NS	***	**	**
Integrated Recommended Dose				
100% RD of P	23.36	86.78	17.13	5.17[a]
30%Pellet+70% RD of P	22.18	84.36	14.75	4.57[b]
30%Mash+70% RD of P	22.47	83.63	13.15	4.52[b]
60%Pellet+40% RD of P	22.47	81.58	13.77	4.03[c]
60%Mash+40% RD of P	22.06	81.57	13.85	3.87[c]
100% Pellet	29.99	80.32	12.59	3.68[c]
100% Mash	22.05	78.77	12.84	3.67[c]
Control	22.35	71.17	11.33	3.05[d]
LSD	8.33	10.84	5.2	0.35
SEM	2.88	3.75	1.38	0.15
P value	NS	NS	NS	***
CV	30.25	11.34	24.82	9.35
Grand mean	23.37	81.02	13.67	4.06

Notes: SEM (±) = Standard Error of mean, LSD=Least Significant Difference, CV = Coefficient of Variation, RD = Recommended Dose, Means followed by different letters within the same column are significantly different at least 5% DMRT, NS, **, *** indicates non-significant, significant at 1%, and significant at 0.01% respectively

3.2.5 Number of pods per plant and seeds per plant

The data on the number of pods per plant and seeds per plant of soybean after harvest is shown in Table 10. There was a significant difference detected in the number of pods per plant for both factors. Soybean pod counts were higher in soils treated with biofertilizer (48.25) than in non-treated soil (45.88). Out of all the treatments, the 100% RD of the chemical had the most pods (51.5), while the control group had the fewest pods (43.00). Likewise, it was discovered that there were considerable differences in the quantity of seeds per plant in both categories. The value of seeds per plant was recorded as highest in 100% chemical RD of P (161.88), while the lowest was recorded in the control (75.32).

Table 3: Number of pods per plant and number of seeds per plant as influenced by biofertilizers, poultry manures, and chemical fertilizers at Mangalpur, Chitwan, Nepal, 2022

Treatment	Pods per plant	Seeds per plant
Biofertilizer		
No Inoculation	45.88^{b}	101.01^{b}
With Inoculation	48.25^{a}	136.66^{a}
LSD	1.65	10.26
Sem	0.572	3.55
P value	**	***
Integrated Recommended Dose		
100% RD of P	51.5^{a}	161.88^{a}
30%Pellet+70% RD of P	47.67^{bc}	121.53^{b}
30%Mash+70% RD of P	48.17^{b}	137.52^{b}
60%Pellet+40% RD of P	48.17^{b}	127.49^{b}
60%Mash+40% RD of P	47.83^{b}	128.72^{b}
100% Pellet	44.5^{cd}	98.73^{c}
100% Mash	45.67^{bcd}	99.49^{c}
Control	43.00^{d}	75.32^{d}
LSD	3.3	20.51
SEM	1.144	7.10
P value	***	***
CV	5.95	14.64
Grand mean	47.06	118.83

Notes: SEM(±) = Standard Error of mean, LSD=Least Significant Difference, CV = Coefficient of Variation, RD = Recommended Dose, Means followed by different letters within the same column are significantly different at least 5% DMRT, **, *** indicates significant at 1%, and significant at 0.01% respectively

3.2.6 1000-seed weight and yield

The data on the thousand seed weight and yield of soybeans after harvest (Table 11). Thousand seed weights were found to be significantly different in both of the factors. The 1000-seed weight of soybean was recorded as highest in bio-fertilizer inoculated soils (153.75 g) than in non-inoculated soil (151.08 g). The 1000-seed weight was recorded highest in 100% RD of P (156 g) which was at par with 30% pelleted poultry manure +70% RD of P (154 g) and 60% pelleted poultry manure+40% RD of P (153.33 g) respectively while the lowest was recorded in control among all the treatments (149.5 g).

Yield was also found to be significantly different in both of the factors. The yield value was recorded as highest in bio-fertilizer-inoculated soils (11.81 qt ha^{-1}) than in non-inoculated soil (10.24 qt ha^{-1}). Similarly, the yield value was recorded highest in 100% RD of P (11.72 qt ha^{-1}) which was at par with 30% pelleted poultry manure + 70% RD of P (11.57 qt ha^{-1}) and 30% mashed poultry manure+70% RD of P (11.33 qt ha-1) respectively, while lowest was seen in control (10.33 qt ha^{-1}) as illustrated in Table 11.

Table 11:1000-seed weight and yield as influenced by biofertilizers, poultry manures, and chemical fertilizers at Mangalpur, Chitwan, Nepal, 2022

Treatment	1000-seed weight (g)	Yield (qt ha^{-1})
Biofertilizer		
No Inoculation	151.08^{b}	10.24^{b}
With Inoculation	153.75^{a}	11.81^{a}
LSD	1.45	0.23
Sem	0.5	0.08
P value	***	***
Integrated Recommended Dose		
100% RD of P	156^{a}	11.72^{a}
30%Pellet+70% RD of P	154^{ab}	11.57^{ab}
30%Mash+70% RD of P	152^{bcd}	11.33^{abc}
60%Pellet+40% RD of P	153.33^{abc}	11.12^{bcd}
60%Mash+40% RD of P	152.5^{bc}	10.95^{cde}
100% Pellet	151^{cd}	10.55^{ef}

Table 11 (cont): 1000-seed weight and yield as influenced by biofertilizers, poultry manures, and chemical fertilizers at Mangalpur, Chitwan, Nepal, 2022		
100% Mash	151[cd]	10.67[def]
Control	149.5[d]	10.33[f]
LSD	2.89	0.47
SEM	1.002	0.16
P value	**	***
CV	1.61	3.61
Grand mean	**152.42**	**11.03**

Notes: SEM (±) = Standard Error of mean, LSD=Least Significant Difference, CV = Coefficient of Variation, RD = Recommended Dose, Means followed by different letters within the same column are significantly different at least 5% DMRT, **, *** indicates significant at 1%, and significant at 0.01% respectively

4. Discussions

4.1 Soil parameters

4.1.1 Soil pH

The use of biofertilizers had a significant impact on the pH of the soil. The lowest soil pH was recorded in bio-fertilizer-applied soil, while higher soil pH was recorded in non-applied soil. Similarly, the combined dose of fertilizer application had a major impact on the pH of the soil. The lowest soil pH was recorded on a combination of 30% pelleted poultry manure and 70% RD of P. The release of nutrients into the soil, the release of organic acids during the breakdown of organic matter, nitrogen fixation, the secretion of organic acids during metabolic activities, and the enhancement of soil fertility are all potential causes of the significant influence of biofertilizers on soil pH.

The significant impact of integrated doses of poultry and chemical fertilizers on soil pH is due to several factors. Poultry manure tends to have a lower pH, due to the presence of organic acids and ammonium compounds. When applied in significant amounts, it can lower the soil pH over time, leading to increased soil acidity (Celik et al., 2010). The combination of poultry manure and chemical fertilizers may lead to increased nutrient uptake by soybean plants. As nutrients are absorbed from the soil, the balance between cations and anions can be disrupted, leading to a change in soil pH (Iqbal et al., 2019).

4.1.2 Soil organic matter

The soil organic matter content was not significantly influenced by bio-fertilizer application as well as integrated dose of fertilizer application. The insignificance of the effect of bio-fertilizers on soil organic matter could be due to the insufficient rate and frequency of application of bio-fertilizers, and the shorter duration of the research.

The lack of significant impact of integrated doses of poultry and chemical fertilizers on soil organic matter of soybean could be due to insufficient rate and frequency of application of bio-fertilizers. The shorter duration of research also might not have allowed enough time for significant changes in soil organic matter to be observed (Chaurasia et al., 2024b). Also, the nutrient composition of these fertilizers is focused on supplying essential nutrients like nitrogen, phosphorus, and potassium rather than adding substantial amounts of organic matter. Indeed, the soil organic matter is influenced by various factors, which encompass soil type, carbon-to-nitrogen (C:N) ratio, Climate, the yearly decomposition of root residues, root exudates and crop stubbles (Condron et al., 2010; El-Ramady et al., 2014; Gentile et al., 2022).

4.1.3 Bulk density

Neither the integrated dose of fertilizer application nor the application of biofertilizer significantly affects the bulk density of the soil. The non-significant effect of bio-fertilizers on soil bulk density could be due to insufficient rate and frequency of application of bio-fertilizers, and shorter duration of the research. The lack of significant impact of integrated doses of poultry and chemical fertilizers on the soil bulk density of soybeans could be due to several reasons (Ghimirey et al., 2025). The rate at which poultry and chemical fertilizers are applied might be insufficient to cause significant changes in soil bulk density (Are et al., 2017). Bulk density is a property that can change gradually over time and may require a prolonged and consistent application of amendments to observe noticeable differences (Saha et al., 2010). Compaction, cropping patterns, tillage, and other soil management techniques can all have an impact on soil bulk density. The impact of integrated fertilizers on bulk density might have been masked by the effects of other agricultural practices (Bandyopadhyay et al., 2010). Since the change in bulk density can take a considerable time to manifest, the duration of the research might not have been long enough to observe significant changes.

4.1.4 Total soil nitrogen

The soil nitrogen content was influenced by bio-fertilizer application. Similarly, the integrated dose of fertilizer applications did not affect soil nitrogen content. The significant impact of bio-fertilizers on total soil nitrogen could be due to nitrogen fixation, release of nutrients including nitrogen into the soil, organic matter decomposition, enhancing nitrogen cycling including nitrogen mineralization, nitrification and denitrification, and crop residue decomposition.

The lack of significant impact of integrated doses of poultry and chemical fertilizers on soil nitrogens could be due to several reasons. Excessive rainfall in the experimental site might have led to nitrogen leaching which reduced the observed impact of integrated fertilizers on total soil nitrogen (Ghimirey et al., 2024c). Soil micro-organisms involved in nitrogen mineralization and immobilization might have influenced the impact of integrated fertilizer application. The nitrogen uptake by soybeans from the soil during their growth could have influenced the change in total soil nitrogen, leading to a non-significant impact of integrated fertilizers. However, the value of total soil nitrogen is higher in an integrated combination of organic and chemical fertilizers. Since organic manure is known to stimulate biological N2 fixation in the soil, the initial application of inorganic fertilizer could have enhanced the activities of microorganisms responsible for N transformation (Sarkar and Rathore, 1992). This could also account for the increase in total soil N (Ladha et al., 1989). The findings are at odds with those of an experiment carried out by which demonstrated the substantial improvement in total soil nitrogen that could be achieved by the combined application of chemical and organic fertilizers (Saha et al., 2010).

4.1.5 Soil available phosphorus

The application of biofertilizer affected the amount of phosphorus that was accessible in the soil. The highest soil available phosphorus was recorded in bio-fertilizer applied soil than non-inoculated soil. Similarly, the available phosphorus in the soil was influenced by the integrated dose of fertilizer applications. The highest soil available phosphorus was recorded in 30% mashed poultry manure +70% RD of P, which was at par with 30% pelleted poultry manure +70% RD of P and 40% RD of chemical P.

The significant impact of bio-fertilizers on soil available phosphorus could be due to the release of organic acids by phosphorus-solubilizing micro-organisms, enhancing nutrient uptake, stimulating phosphorus cycling including mineralization and immobilization processes, and the release of root exudates that help to release bound phosphorus and increase its availability (Billah et al., 2019). The significant impact of integrated doses of poultry and chemical fertilizers on soil available phosphorus of soybean could be due to several reasons. Both poultry and chemical fertilizers contain phosphorus which increases the available phosphorus in the soil. Also, continuous application of phosphate fertilizer can result in a buildup of phosphorus levels in the soil, as only 15 to 20 % of the applied fertilizer is used up by the plants (Jain and Trivedi, 2005). A group researcher reported that organic fertilizers had a favorable influence on the availability of phosphorus (Roy et al., 2001).

4.1.6 Soil exchangeable potassium

The soil available potassium in the soil was not significantly influenced by bio-fertilizer application as well as an integrated dose of fertilizer application. The lack of significant impact of bio-fertilizers on soil exchangeable potassium could be due to a lack of bio-fertilizers containing potassium-releasing compounds, insufficient rate and frequency of application of bio-fertilizers, and shorter duration of the research.

Similarly, the lack of significant impact of integrated doses of fertilizer application could be due to various factors. Soil exchangeable potassium may require a prolonged and consistent application of amendments to observe noticeable differences; the duration of the research might not have been long enough to observe significant changes. According to a study, in some soils (esp. sandy loamy or clayey), potassium can become fixed or immobilized, making it less available for plant uptake, which limits the effectiveness of added potassium from fertilizers, including poultry manure (Liu et al., 2010). Consequently, despite applying integrated doses of fertilizers, the net impact on exchangeable potassium may be low. The result contradicts the experiment done by which showed a significant impact of integrated application of fertilizers (100%NPK+Lime+Biofertilizer+FYM) in increasing soil exchangeable potassium (Saha et al., 2010).

4.2 Plant parameters

4.2.1 Plant height

Bio-fertilizers did not have any significant impact on the plant height of soybean at 30DAS, 60DAS, and 90DAS respectively while it had a significant impact at 120DAS. Plant height at 120 DAS was recorded as higher in bio-fertilizer-inoculated soils than in non-inoculated ones. The results are similar to the experiment done by in which the plant height increased significantly in Bradyrhizobium-inoculated treatments than the un-inoculated one (Alam et al., 2009; Egamberdiyeva et al., 2004).

Similarly, an integrated dose of fertilizers did not have any significant impact on the plant height of soybean at 30DAS, while a significant impact was found at 60DAS, 90DAS, and 120DAS. Plant height at 60 DAS was recorded highest in 30% pelleted poultry manure + 70% RD of P which was at par with 30% mashed poultry manure + 70% RD of P, 40% RD of P, 60% pelleted poultry manure+40% RD of P, 60% mashed poultry manure +40% RD of P, and 100% pelleted poultry manure respectively. Plant height at 90 DAS was recorded highest in 40% RD of P, which was at par with 30% pelleted poultry manure + 70% RD of P. Plant height at 120 DAS was recorded highest in 100% RD of P. The results corroborate those of who demonstrated the noteworthy impact of the combined application of chemical and biological fertilizers on elevated soybean plant height (Alam et al., 2009). Compared to other treatments, the plant height of the control group was the lowest during all growth stages. The significant impact of bio-fertilizers on the plant height of soybeans is due to their potential to enhance nutrient uptake, stimulate root development, increase disease resistance, and regulate plant growth hormones. A group researcher speculate that the notable increase in soybean plant height in soil injected with biofertilizer may be attributable to the increased availability of macro- and micronutrients from both organic and inorganic sources (Dash et al., 2005; Dipak et al., 2018).

The increased plant height in Bradyrhizobium and phosphorus-solubilizing bacteria (PSB) plots could be due to the enhanced availability of nitrogen and phosphorus which promoted the growth of the plants (Srivastava, 1995). The significant impact of integrated doses of poultry and chemical fertilizers on the plant height of soybeans is probably due to a more balanced supply of nutrients, higher nitrogen contribution, slow release of nutrients, and synergistic nutrient effects. Poultry manure is rich in organic nitrogen, while chemical fertilizers often contain synthetic nitrogen compounds. The integration of both sources boosts the nitrogen and phosphorus availability in the soil, promoting vigorous vegetative growth of the plant (Srivastava, 1995).

4.2.2 Number of branches and number of leaflets

Bio-fertilizers did not have any significant impact on the number of branches at maturity, while integrated doses of fertilizers had a significant impact on the number of branches at maturity of soybeans. The number of branches was recorded highest in 30%Pelletsellet+70% RD of P which were at par with 100% RD of P, 30% Poultry mash+70% RD of P, 60% Poultry Pellet+40% RD of P, 100% Pellets and100% Mash respectively, while lowest was recorded in control among all the treatments. The results were in agreement with who showed the significant impact of integrated fertilizer on the increased number of branches at maturity in soybeans (Dipak et al., 2018).

Similarly, Biofertilizers did not have any significant impact on the number of leaflets at maturity. The number of leaflets was recorded as highest in 100% RD of P, which was at par with 30% pelleted poultry manure + 70% RD of P, while the lowest was seen in the control. The results are similar to who showed the significant impact of integrated fertilizer application on the increased number of leaflets at maturity in soybeans (Dipak et al., 2018).

The significant impact of bio-fertilizers on the number of leaflets in soybean plants is due to improved nutrient uptake, enhanced photosynthesis, hormonal regulation, root development, induced resistance, stress tolerance, and availability of micronutrients. The positive influence of bio-fertilizers on multiple aspects of plant growth and development collectively results in increased leaflet production. The significant impact of integrated doses of poultry and chemical fertilizers on the number of branches of soybean is probably due to improved photosynthesis and synergistic nutrient effects. The combination of poultry and chemical fertilizers stimulates root development in soybean plants. A strong root system facilitates the plant's efficient uptake of nutrients and water, which increases the number of branches and lateral shoot growth (Ghimirey et al., 2024d). The higher quantity of leaflets may have resulted from the availability of more macro- and micronutrients from both organic and inorganic sources, which speed up the metabolism of N, P, and K and improve nutrient absorption and distribution (Dash et al., 2005; Dipak et al., 2018).

4.2.3 Number of nodules

Bio-fertilizers did not have any significant impact on the number of nodules of soybean at 30 DAS, while they had a significant impact at 60 DAS, 90 DAS, and 120 DAS, respectively. The number of nodules was recorded higher in bio-fertilizer inoculated soils at 60 DAS, 90 DAS, and 120 DAS respectively than in non-inoculated soils. Similar results were observed in suggesting that the inoculation of legume plants with rhizobium increased nodulation (Dashti et al., 1997; Egamberdiyeva et al., 2004; Zhang et al., 1996).

Similarly, an integrated dose of fertilizers did not have any significant impact on nodules of soybean at 30 DAS, 60 DAS, and 90 DAS respectively, while it had a significant impact on 120 DAS. The number of nodules at 120 DAS was recorded highest in 100 % RD of P which was at par with 30% pelleted poultry manure + 70% RD of P. Number of nodules was seen lowest in control than other treatments at all stages of growth. The number of nodules decreased gradually from 60 DAS to 120 DAS in all the treatments. The lowest number of nodules was recorded in 120 DAS, probably due to the senescence of the roots during the ripening stages of the crop (Alam et al., 2009).

The significant impact of bio-fertilizers on the number of root nodules in soybean plants is due to improved nitrogen fixation, increased nutrient availability, root system development, hormonal regulation, and stress tolerance. The significant impact of integrated doses of poultry and chemical fertilizers on the number of root nodules of soybean is probably due to enhanced synergistic nutrient effects, stimulation of root growth, adequate availability of phosphorus and potassium, which promote root nodulation, and enrichment of organic matter, which promotes growth and activity of beneficial micro-organisms.

4.2.4 Dry weight of nodule per plant

Bio-fertilizers did not have any significant impact on the dry weight of nodules at 30 DAS while they had a significant impact on 60 DAS, 90 DAS, and 120 DAS, respectively. The dry weight of root nodules was recorded as higher in bio-fertilizer-inoculated soils at 60DAS, 90DAS, and 120DAS, respectively, than in non-inoculated soils. A group researcher observed similar results in which the bradyrhizobium inoculation of soybean increased the dry weight of root nodules by about 15% compared to the non-inoculated one (Bai et al., 2002).

Similarly, bio-fertilizers did not have any significant impact on the dry weight of nodules of soybean at 30 DAS, 60 DAS, and 90 DAS, respectively while it had a significant impact on 120 DAS. The dry weight of nodules of soybean at 120 DAS was recorded highest in 100% RD of P. Dry weight of nodules was seen lowest in control at all stages of growth.The significant impact of bio-fertilizers on the number of root nodules in soybean plants is due to improved nitrogen fixation, increased nutrient availability, root system development, hormonal regulation, and stress tolerance. According to study, the significant increase in dry matter could be due to the increased nitrogen fixation efficiency (NFE) in plants of the biofertilizer-inoculated treatments (Bai et al., 2002). The significant impact of integrated doses of poultry and chemical fertilizers on the dry weight of root nodules of soybean is probably due to enhanced synergistic nutrient effects, stimulation root growth, adequate availability of phosphorus and potassium which promote root nodulation, enrichment of organic matter which promotes growth and activity of beneficial micro-organisms.

4.2.5 Number of pods per plant and seeds per plant

There was a significant difference found in the number of pods per plant for both factors. In comparison to non-inoculated soil, soil treated with biofertilizer had the greatest reported number of soybean pods. The 100% RD of P showed the maximum number of pods. Likewise, it was discovered that there were considerable differences in the quantity of seeds per plant in both categories. In 100% RD of chemical P, the value of seeds per plant was maximum. Similar results were seen by in their study of soybeans, wherein the integrated application of 50% of the prescribed fertilizer dose along with bio-fertilizer (bradyrhizobium) considerably increased the quantity of pods and seeds per plant (Alam et al., 2009).

Similarly, some researchers make experiment on soybean plants treated with bradyrhizobium and PSB (phosphate solubilizing bacteria) revealed an increase in the quantity of pods and seeds per plant (Jain and Trivedi, 2005). Similar outcomes were noted by who noted that the number of pods per plant increased considerably in soybean plants treated with bradyrhizobium inoculants (Tomar et al., 2012). Biofertilizers may have a major effect on the number of soybean pods produced per plant by enhancing nutrient availability, increasing nutrient uptake, developing root systems, regulating hormones, mitigating stress, producing synergistic effects, enhancing photosynthesis, and suppressing disease.

The value of seeds per plant was recorded highest in 30% Pelleted poultry + 70% RD of P which was at par with 100% RD of P. The significant impact of bio-fertilizers on the number of pods per plant and number of seeds per plant of soybean is probably due to improved nutrient availability, increased nutrient uptake, root system development, hormonal regulation, stress mitigation, synergistic effects, improved photosynthesis, and disease suppression. This improvement in pod formation and seed formation within the pod is critical for boosting soybean yield potential. The improvement in yield attributes that resulted from applying phosphorus may have been caused by abundant nodulation, which boosted nitrogen fixation and had a good effect on the photosynthetic rate and organs of the soybean plant (Srivastava, 1995).

4.2.6 1000-seed weight and yield

Thousand seed weights were found to be significantly different in both of the factors. The 1000-seed weight of soybean was recorded as higher in bio-fertilizer-inoculated soils than in non-inoculated soil. The 1000-seed weight was recorded highest in 100% RD of P which was at par with 30%Pelletsellet+70% RD of P and 60% Poultry Pellet+40% RD of P respectively while the lowest was recorded in control among all the treatments. The results corroborated those of who noted a noteworthy rise in 1000-seed weight in soybean plants treated with bradyrhizobium (Podder et al., 1999). The results of a group researcher also showed an insignificant increase in 1000-seed weight in biofertilizer-inoculated treatment in combination with chemical fertilizers (Alam et al., 2009).

Yield was also found to be significantly different in both factors. The yield value was recorded as higher in bio-fertilizer-inoculated soils than in non-inoculated soil. The findings reflected those of studies conducted by which showed a higher yield increase in biofertilizer-inoculated soil (Egamberdiyeva et al., 2004; Rahmani and Rastin, 2001). Similarly, the yield value was recorded highest in 100% RD of P, which was at par with 30% Poultry Pellet + 70% RD of P and 30%Mash+70% RD of P, respectively, while the lowest was seen in the control.

The significant impact of bio-fertilizers on the yield of soybean plants is due to improved nutrient availability, increased nutrient uptake, root system development, hormonal regulation, stress mitigation, synergistic effects, improved photosynthesis, and disease suppression. Beneficial microorganisms like rhizobacteria and other microbes that promote plant growth are used in microbial interventions for nutrient management to increase crop output by increasing nutrient availability and uptake efficiency productivity (Bhattacharya et al., 2008; Paramesh et al., 2023).

There are likely several reasons why integrated doses of poultry and chemical fertilizers have such a large effect on TGW and soybean production. Among the additional benefits that organic matter offers over NPK alone are increased microbial activity, better availability of critical macro- and micronutrients like S, Zn, C, and B that are not supplied by conventional NPK fertilizers, as well as decreased nutrient losses from the soil. These factors could be attributed to the increased soybean yields (Paramesh et al., 2023).

5. Conclusion

Thus, the integrated use of bio-fertilizers, poultry manure, and chemical fertilizers enhanced the effect on the growth, yield, and soil parameters of soybeans. The inoculation of bradyrhizobium and phosphate-solubilizing bacteria in soybean contributed to better total soil nitrogen, soil available phosphorus, plant height, number of nodules, dry weight of root nodules, number of pods per plant, seeds per plant, thousand seed weight, and yield, respectively. Similarly, the application of 100% recommended dose (RD) of chemical phosphorus (P), 30% pelleted poultry manure +70% RD of P, and 30% mashed poultry manure +70% RD of P was found effective for better soil-available phosphorus, plant height, number of branches and leaflets at maturity, number of nodules at various growth stages, number of seeds per plant, thousand seed weight and yield respectively. Overall, the findings highlight the potential benefits of integrating bradyrhizobium and PSB with appropriate recommended doses of phosphorus for optimizing soybean production.

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Conflict of Interest

The authors hereby declare that they possess no conflict of interest in this paper.

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